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On the development of an improved daylight illumination recorder.

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(Meteorological Office)

AIR MINISTRY

METEOROLOGICAL RESEARCH COMMITTEE

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On the development of an improved daylight illumination recorder

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Summary

The imperfections of the present daylight recorder, in use at Kew Observatory and Victory House, are briefly reviewed and a critical analysis is made of existing calibration techniques.

The development of the improved instrument is shown to follow logically from considerations of ease of maintenance and calibration, and from the requirement that its indicated readings should not need to be adjusted retrospectively.

Some evidence as to the accuracy of the Kew daylight measurements is discussed. Finally, the first available comparisons of readings from the two instruments are given for various meteorological conditions.

1. Introduction

It may be convenient first to restate the problem. The quantity to be measured is the brightness of daylight in the ordinary sense of the words - that is, as perceived by the human eye. The sensitivity of the eye varies greatly with the wave-length of the incident light, so that any instrument used to measure illumination must have a response which varies in the same way. This can be achieved by using a photo-electric cell in combination with a suitable optical filter. In the Kew instrument the daylight is first received on a horizontal disc of translucent material, and the filter-photocell combination is exposed only to the light from under the surface of this disc. The instrument is not an absolute one, but must be calibrated by exposing it to a known artificial illumination.

In a previous report by Blackwell (1953), an attempt was made to eliminate the systematic errors inherent in measurements made with this instrument, by computing the necessary corrections and applying them retrospectively to the tabulations.

During the development of the improved instrument described below, a further source of systematic error became apparent. This error, which is considered in section 3(b), arises during calibration from the fact that the opal glass or plastic discs used do not act as perfectly diffusing layers. The existence of some such error was foreshadowed in a report by Blackwell, Eldridge and Robinson (1954) in which the mutual consistency of radiation and illumination measurements at Kew Observatory was examined. Estimates of this error, derived experimentally and deduced analytically, will be shown to be in fair agreement.

The final results obtained with the present (Mark II) recorder, corrected for all known systematic errors, will be compared with those from the improved (Mark III) instrument for various meteorological conditions.

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2. Imperfections of the Mark II instrument

(a) Temperature coefficient of the photocell and filter

This was determined accurately, as described by Blackwell (1953), and found to be - 0.3% per 1°C. at normal ambient temperatures.

(b) Cosine law response of receiver

The largest single source of error results from the markedly imperfect cosine law response of the receiving unit (diffusing plate + protecting hemispherical glass dome). The overall response was therefore redetermined, using a lamp at about two metres distance and measuring the photocell output with a precision potentiometer and galvanometer of high sensitivity. The final curve was indistinguishable from that given by Blackwell (1953).

It is of interest to note here an essential difference between a blackened thermopile and a photometer of the present type, even though both have perfectly matt receiving surfaces (as viewed from above). The former has a cosine law response, whereas the latter shows a marked departure from such a law. Some insight into this difference may be gained by considering the analogous case of a thick stratified cloud. Mr. D.B. Lake, in an unpublished paper, has deduced theoretically that in such a case the total transmitted light, $T(\theta)$, depends on the angle of incidence, θ, of the light falling on the top of the cloud, in the following way:

$$T(\theta) \propto \cos\theta\,(1 + k\cos\theta)$$

where k is probably close to the value 2. Fig. 1 shows the experimentally determined response lying between the curves for $\cos\theta$ and $\cos\theta\,(1+2\cos\theta)$. One reason why the actual response is better than that predicted may be due to the fact that the diameter of the diffusing plate is of comparable size to that of the dome. Indeed, this is one method by which some degree of cosine-correction may be effected, since more of the light, falling on the disc, strikes the dome nearly perpendicularly at low elevations, than at higher elevations.

It is therefore necessary, with photometers of this type, to devise such means of cosine-correction as will raise the response curve to approximate coincidence with that of a perfect receiver (i.e. one obeying the cosine law).

(c) Spectral sensitivity

Allowance is made for the difference in colour-temperature of natural daylight (6000°K) and the calibrating lamps (2500°K) as described by Blackwell (1953). The spectral sensitivity data supplied by the N.P.L. are obtained from the transmission characteristics of the filter and the response of the photocell as determined by a monochromator. There is thus a small uncertainty due to the fact that the spectral response of the cells used may be slightly different for the higher values of illuminance when normally exposed from the response at the extremely low intensities obtained with a monochromator.* It is thought, however, that the error involved is small.

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* An effect pointed out by Dr. J.S. Preston of the N.P.L.

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3. Calibration errors

The instrumental response to light at any given angle is related to that for normal incidence by the empirically determined response of the receiver. The photometric measurements are therefore based on the routine calibrations which are carried out at normal incidence. The standard lamps

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used in the laboratory have remained unchanged within the limits of accuracy of the N.P.L. calibrations (± 2%). It is in the method of their use that a further source of error has become apparent (see section 3(b)).

The lamps produce an illumination which is known at points on the optical axis at distances considerably greater than the dimensions of the filament. Hitherto, a two-stage calibration technique has been used to overcome the difficulty of producing in the laboratory a known illumination comparable in intensity with natural daylight. A non-standard 100 watt lamp is first used to establish the variation of cell output with intensity, using the cell + filter unit alone and invoking the inverse-square law. In this way, the full working range (for the unit, when mounted in its normal position inside the recorder) is covered, up to effective intensities of about 200 kilolux (outside the recorder).

To minimise casual errors of calibration in the future, the corrections for non-linearity for each month have been embodied in a table based on a large number of such calibrations (Fig. 2). The percentage differences, between the values of cell sensitivity derived from the tangents at the origin and the best straight lines, drawn for the appropriate ranges of intensity for each month, lie between 0% and 3% as follows:

Table I - Non-linearity corrections

Month	J	F	M	A	M	J	J	A	S	O	N	D
Percentage	0	½	1	1¾	2½	3	2½	1¾	1	½	0	0

The stability of the class of cells used is such that the general form of the curves appears to remain unchanged while the sensitivity undergoes a smooth and gradual decrease. The use of Table I can therefore replace the first stage of the calibrations.

The second stage would ideally consist of producing a known high illumination on the complete assembled recorder, using a parallel light beam. It has been the practice to set up the standard lamp at about 25 cm. from the diffusing plate in order to produce an illumination of some 40 kilolux. The problem remained to deduce the instrumental factor (microamps per kilolux) from such an arrangement. Two aspects of the optical system must be considered: the illumination of the diffusing plate, and the transmission characteristics of the pot-opal glass, bearing in mind any effects which might be introduced by the use of a non-parallel light beam.

(a) Illumination of the diffusing plate

The intensity of illumination over the receiving area falls away from the central point toward the edges for the following reasons:

(i) because of the greater distances from the lamp to off-centre points on the opal disc

(ii) because of the cosine effect at the opal disc for off-axis rays

(iii) because of the polar diagram of the emitted light from the lamp.

In slight opposition to these factors is the effect of reflection at the glass dome, which is less for an off-axis ray (to a given point on the opal disc) than for a ray which is parallel to the optical axis.

The variation of illumination over the opal disc was previously determined (with some difficulty owing to lack of sufficiently sensitive apparatus) in the

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following manner. A probe, consisting of a photocell masked down to a 5 mm. square, was moved from side to side of the illuminated area immediately behind the diffusing plate. A difference of 2% was found between the illumination at the centre and at the edge of the effective area (defined by a diaphragm of 2in. diameter behind the diffusing surface). An allowance of 1% was made for the average effect.*

* Strictly, this should have been about 1½% after weighting the larger areas near the edge of the disc.

In the present investigation, this experiment was repeated by using the actual photocell in the recorder and moving a 4 mm. square aperture across the front surface of the opal disc (Fig. 3a) with the lamp at the normal calibration distance of 25 cm. The very small output from the photocell was amplified by a D.C. galvanometer-amplifier to give what we shall call "curve 1". This represents the combined effect of instrumental response plus the required variation of illumination on the opal disc. The instrumental response behind the diffusing surface is affected by:

(i) the polar diagram of the diffuse transmitted light

(ii) the varying distance from the parts of the opal disc to the photocell + filter unit

(iii) the cosine effect at the photocell for rays not at normal incidence.

Secondly, the 4 mm. aperture was again moved across the diffusing plate, but this time the lamp was given equal displacements in the same sense, so that the instrumental response alone was determined (Fig. 3b). The resulting response, "curve 2", was then subtracted algebraically from "curve 1" to give the same 2% variation previously found.

(b) Transmission characteristics of the pot-opal glass

During the development of the new instrument, it was decided to determine the instrumental factor by means of an extrapolation technique. This was done by plotting the uncorrected factor (in microamps per kilolux) against distance of the lamp, on the assumption that the illumination at the opal disc was uniform. By extrapolating to get the value at infinity (i.e. for a parallel beam of light), it was found, unexpectedly, that this value was considerably higher than the uncorrected value corresponding to a distance of 25 cm. (Fig. 4). The extrapolation method was therefore repeated with the old instrument and a difference (in the same sense) of about 7½% was found, instead of the 1½% expected.

Since this work was done, our attention has been drawn * to an earlier paper by Poole and Atkins (1935) in which they make the following comments:

> "With most cells, the agreement with the inverse square law is not so good, the results at 10 cm. being generally too small by some 5-10% compared with the values found at 40 or 50 cm., even when the calculated correction has been made for the sizes of the source and window. Several suggestions may be offered ..... If the diffusing power of the opal glass were inadequate it would not be correct to take the distance from the filament to the glass as the effective distance, but rather something greater, as the cell is behind the glass."

These authors did not, however, come to any definite conclusions on the matter.

* By Mr. H. Hack of the Glasshouse Crops Research Institute, Littlehampton.

The assumption that the opal glass acted as a perfect diffusing layer was therefore investigated. Reverting to the analogous case of a layer of dense cloud, we should expect a certain polar diagram (such as the zenith light being three times the light from the horizon), which would remain

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unchanged whatever the directive qualities of the light incident on the top of the cloud.

In order to test the transmission characteristics of the pot-opal glass, an experiment was devised (Fig. 5a) as follows. A $\frac{1}{2}$ in. square aperture was moved across the front surface of the opal glass between two alternative positions at opposite ends of a horizontal diameter of the circular plate. The lamp was placed at about $1\frac{1}{2}$ metres from the recorder which was mounted normal to the beam. In order to eliminate any errors caused by misalignment, the ratio of the photocell outputs was noted for the two positions of the aperture.

The recorder was then pivoted on a turn-table about a vertical axis until the diffusing plate was offset 15° from the normal position (Fig. 5b). The geometry of the experiment was such that no allowance was required for the polar diagram of the lamp, and only a negligible correction for the difference in reflection at the two positions. When allowance had been made for the cosine effect at the two positions and for the difference in distance from the lamp, the ratio previously noted above was found to have changed by about 2%; this can only be attributed to the spatial shift of the polar diagram of the transmitted light. The magnitude of the effect is not known with sufficient accuracy to apply a quantitative correction to the calibration results at 25 cm; it is only necessary to realise the source of error and to modify the experimental technique of future calibrations accordingly, i.e. by using the extrapolation method described earlier in this section.

One remaining geometrical factor should be mentioned as it may contribute to the difference between the instrumental factors at 25 cm. and at infinity. A glass sheet interposed between the lamp and the diffusing plate would cause an 8% reduction in intensity due to reflection losses. It was noticed that the hemispherical dome caused a reduction of only 2%. The pattern of inter-reflections, between the diffusing surface and the dome, which produces this effect might well be significantly modified by close proximity of the lamp.

4. Development of the Mark III recorder

The present prototype model overcomes the imperfections of the Mark II instrument insofar as it faithfully records the physical quantity to be investigated, without the need for a system of retrospective corrections. Attention has also been given to facility of maintenance, reduction in size and weight, simplification of construction and ease of calibration.

Owing to the excessive size of certain component parts, there is still room for further improvement of design but we are more concerned here with the physical performance of the instrument. As foreshadowed earlier (Blackwell 1953), the main modifications are concerned with elimination of temperature effects and cosine law imperfections.

(a) Temperature effects

To achieve the highly desirable result of an instrument registering directly in photometric units, it was decided not merely to arrange to record the working temperature of the photocell but to control this thermostatically at a single practicable value. The difficulty arises that this temperature must be higher than any value which might be reached under natural conditions, and yet be below the danger limit where destructive absorption of infra-red radiation by the selenium barrier-layer photocell becomes of importance.

Previously, the Mark II instrument had been sited on the main roof of Kew Observatory, which is covered with lead. On days of strong insolation, the working temperature of the cell rose as much as 30°F. above screen temperature, aided no doubt by the enhanced radiation for the roof. As reported by Blackwell (1954), the site of the horizontal surface instruments at Kew has now been transferred to a circular platform above the Observatory dome. One useful result of this, not considered at the time, is that the reflected radiation is much reduced and that the average temperature at this greater height is several degrees

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lower. A controlled temperature of 100°F. was therefore chosen to ensure efficient thermostatic operation, and this value is about 20°F. below the danger limit usually quoted in the literature.

To achieve this control of temperature, the cell and filter are mounted in an inner chamber which is sealed with a clear glass lid and retaining ring immediately above the filter (Fig. 6). The cylindrical chamber is heated by a glass-insulated coil of resistance wire, connected in series with a cartridge thermostat which is screwed into the cavity below the photocell mounting. The resistance element and thermostat are connected to the mains supply via a ballast lamp of suitable wattage which also acts as a visual monitor on the functioning of the thermostat.

During the initial testing period, a recording thermocouple was placed on the photocell mounting. Observations of the amplitude of the temperature cycles showed that this could be minimised by selecting ballast lamps of suitable wattage according to season. The extremes of working temperature recorded are 98°F. and 102°F. In setting up the instrument, the adjustable cartridge thermostat is fitted with an extension rod which can be rotated by means of a divided wheel, readily accessible below the instrument.

When a calibration has to be done in the laboratory (it is not intended that this should be done more than once a year in future), the instrument can be disconnected from the mains supply at the site and reconnected in the laboratory with little loss of time. The temperature does not change appreciably in this short interval and the calibration can be started immediately. At these occasional times when a check of the degree of non-linearity of the recorder is required, the inner chamber is mounted on the optical bench and the inverse square law can still be invoked in spite of the intervening clear glass cover. The temperature-controlled chamber is rigidly attached to the main base of the instrument through which pass the leads to the mains supply, the output leads from the photocell, and the thermocouple leads to potentiometer or recording galvanometer.

(b) Cosine law correcting-device

Many methods of obtaining improved responses (more in keeping with the cosine law) from receiving surfaces of photometers have been tried. The best results which can be achieved by the various methods are very similar. Among the more common of these devices may be mentioned:

(i) roughened upper surfaces of the diffusing material chosen

(ii) convex domes which are not hemispherical

(iii) roughened inner surfaces of hemispherical domes

(iv) setting the disc of diffusing material with its upper surface slightly above the level of the surrounding metal cover so that it receives some of the incident light on its edge.

Method (i), which was used in the Mark II recorder, is not sufficiently effective by itself (see section 2(b)), nor is method (ii). Methods (i) and (iii) require grinding or sand-blasting (techniques which must be carefully controlled if consistent results are to be obtained), and suffer from the drawback that the response characteristics change irreversibly if the surfaces get clogged with dirt or grease. Method (iv) has been tried successfully by Pleijel and Longmore (1952) in conjunction with method (i), but the instrument was intended as a non-weatherproof, portable probe for indoor determinations of daylight factors. It has also been tried alone by Foster (1951) with good results. Neither of these instruments has a protecting dome, the pot-opal receiving surface of the latter model having to be carefully sealed to prevent ingress of moisture. In addition, its bevelled housing allows light to be received from below the horizon.

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After careful consideration of all known methods and their respective advantages, it was decided:

(i) to use the "edge-effect" compensating-device of method (iv)

(ii) to use a clear glass hemispherical dome, mounted above a circular diffusing disc of diameter comparable with that of the dome

(iii) to dispense with all roughened surfaces, whether of the diffusing material or of the dome.

By this choice of design details, the construction is simplified as much as possible, sealing of the instrument is made straightforward and the cleaning of component parts can be carried out without affecting the response characteristics. After some initial experiments with pot-opal glass discs, it was soon realised that closer tolerances could be obtained by machining diffusing opal plastic, which also has non-selective transmission over the visible range.

The total transmission through the opal plastic, being much higher than that of the pot-opal glass, enables most of the underneath surface to be masked out with a centrally placed opaque diaphragm. This, in turn, increases the correcting power of the edge-effect relative to the response of the polished flat receiving surface. The amount by which the plastic disc must finally be set up, above the level of the surrounding metal cover, is nevertheless fairly critical. A micrometer adjusting ring with a 1 mm. screw thread is used to support the diffusing plate. The ring has a circular scale, divided into fortieths of a revolution, which permits rapid adjustments of height to be made to one thousandth of an inch.

The glass dome protects the receiving surface; and the air space between them, though isolated from the rest of the instrumental cavity, is connected to two small tubes at either side (Fig. 6). These can be used in conjunction with a dry-air pump to remove condensation in a matter of seconds. The whole unit is mounted on the outer case of the recorder which protects the heating element round the inner chamber. The interspace does not have to be sealed from the outside atmosphere, but the air in the temperature-controlled chamber is connected to a drier-bulb containing silica-gel.

Initial tests on the cosine law characteristics of the light collector showed that, to obtain a gradually changing family of response curves, it was essential that the diffusing material be worked to a close running fit with the surrounding mounting. This requirement led to the use of a diffusing opal plastic (Perspex No. 040, made by Imperial Chemical Industries Ltd., was the eventual choice), which could be accurately turned to the correct size.

To show in detail how the present cosine-correcting device can produce an almost theoretically perfect response with polished opal perspex, two typical curves are plotted in Fig. 7a. The response at any given angle of elevation is expressed as a percentage of that for a perfect receiver. For comparison, the response curve of the Mark II recorder is also plotted, and shows the inadequacy of the method of roughening the upper surface of the diffusing material as a means of cosine correction.

It is not sufficient to choose the response characteristic which appears to be the best in Fig. 7a. We are concerned with the total luminous flux on a horizontal surface and must weight the instrumental response according to the contribution, to that total flux, of each zone of the sky. As a first step in this assessment, the curves are redrawn in Fig. 7b, which shows the calculated response of these different receiving surfaces in the ideal case of light coming from a uniformly illuminated hemisphere of sky. The response to the light from that part of the sky lying between zenith angles of θ and $\theta + d\theta$ will be proportional to $E_\theta . \sin\theta . \cos\theta . d\theta$, where E_θ is the efficiency of the receiving surface, i.e. the ratio of actual response to light from direction θ to the corresponding response of a perfect receiver. In Fig. 7b, the value of $E_\theta . \sin\theta . \cos\theta$ is plotted against θ for a perfect receiver ($E_\theta = 1$) and for both the Mark II and

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the finally selected Mark III instruments. It is at once evident how much closer the Mark III instrument is to the perfect receiver.

As reported by Blackwell (1953), the Mark II instrument registered only 89% of the natural diffuse sky light, and would have recorded 87% of the light from a uniform diffuse hemisphere. By means of the relatively simple correcting-device just described, the Mark III recorder is made to register 100% of the luminous flux from the same ideal hemisphere.

Fortunately, the selected response curve which gives this result is also one which departs but little from the true curve between angles of incidence from 0° to 80°. Beyond this point, contributions from the sky light are energetically of little importance, nor is the effect of the direct solar beam of great significance. At higher solar altitudes, when the direct component is dominant, the accuracy is of the order of ± 2%. To maintain this degree of accuracy, the levelling of the receiving surface must be periodically checked by reference to the circular spirit-level attached to the side of the outer case.

(c) Routine use and standardisation

The air space under the dome may require to be connected to a dry air pump at infrequent intervals in order to remove condensation. The silica-gel drier will need to be renewed every month or two, since excessive moisture will permanently affect the photocell sensitivity. The ballast lamp in the heating circuit should be noted as "on" or "off" at suitable intervals and a permanent record kept in order to check the functioning of the thermostat.

About once a year, it will be advisable to check the degree of non-linearity of the photocell response, as described in section 3. At other times, a portable sub-standard of essentially the same design will be set up alongside the continuously recording instrument and its output recorded on the same thread-recorder. The same portable instrument could also be used to standardise the daylight recorders at other stations.

Calibration of the portable sub-standard will be carried out in the laboratory, using standard lamps at about two metres from the receiving surface. It has been found that the uncorrected instrumental factors reach a steady value at this distance and that the photocell output is still large enough to be measured accurately with a precision potentiometer and galvanometer of high sensitivity. A typical curve, obtained by the extrapolation method, is given in Fig. 4.

5. Accuracy of the Kew standard of photometry

Blackwell (1953) estimated that the means of large numbers of observations quoted by Blackwell (1953) should be correct to within ± 5%. In a report by Blackwell, Eldridge and Robinson (1954), it was found that mutual consistency of the radiation and illumination measurements (made at Kew) could only be obtained on the assumption that the latter data were about 5% too high.

The radiation measurements consisted of total and diffuse radiation on a horizontal surface and the intensity of the direct solar beam for the whole spectrum and for two spectral regions. These, and measurements of the total illumination of a horizontal surface, were compared with the results to be expected from an extraterrestrial distribution of solar radiation proposed by Nicolet (1951a, 1951b) and the predicted attenuation by a model atmosphere. Similar estimates of the additional attenuation by the actual atmosphere were obtained by several methods, involving the use of different combinations of the available data. Anomalous results, however, occurred in the method involving the illumination record, and it was here that mutual consistency could only be regained by reducing the daylight measurements by 5%.

There is little external material with which to compare the Kew values, but those results found in cloudless conditions by Lopukhin (1953) at Tashkent (a locality probably less subject to smoke but more subject to dust haze than Kew) are some 5-10% less. The values of luminous efficiency of daylight computed by Blackwell (1953, 1954) are also somewhat higher than those usually seen in the literature.

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It is of interest that this later work, described above in section 3(b), suggests that the previously quoted results should be reduced by about 6%. We therefore believe that the present standard of photometry (now embodied in the measurements made at Kew with the Mark III recorder) is a close approximation to the photometric standard as defined internationally.

6. Comparison of results from old and new instruments

It is not intended to make an exhaustive comparison of the performance of the two instruments, because the scheme of corrections applicable to readings of the Mark II instrument was intended only for means of large numbers of observations. In addition to this limitation, these corrections have been partially invalidated by subsequent changes in the local operating conditions, among which are:

(i) the repainting of the Observatory dome in a much brighter cream than before

(ii) the installation of central heating in the building

(iii) departures in the day to day climate from the averages on which the original corrections were based

(iv) the different sites of the two instruments.

The effect of item (i) is to increase the back-reflection from the dome onto the old instrument. It was previously estimated that this just about counter-balanced the loss due to obstruction. Now it may overcompensate by some 1-2% on sunny days, especially when there is little cloud. Item (iv) relates to the fact that the new recorder is mounted above the dome, receives no reflected light and, in addition, loses some 1-2% because of obstruction by the anemometer mast.

In item (ii), the presence of central heating in the laboratory tends to raise the calibration temperatures above those on which the old corrections were based, particularly in winter. Since the temperature coefficient of the photocell is negative, the present readings of the Mark II recorder will therefore be about 1-2% lower than previous readings in winter, the effect acting in opposition to the earlier ones.

Apart from these largely random errors, and those arising inevitably from item (iii), the Mark II data have been processed according to the scheme of corrections described by Blackwell (1953). In addition, allowance has now been made for the newly discovered lack of diffusing power of the opal glass, the values being reduced by 6% on this account. The Mark III data have not been processed in any way, since the calibrations of this instrument have always been based on the extrapolation method.

Comparisons were made of the records obtained under cloudless and overcast skies (selected by the same criteria as those described by Blackwell, 1953) during the period July - September, 1955. The results are shown in Fig. 8, and broadly confirm the predictions made above.

7. Conclusions

It may be helpful at this stage to bring together the essential points which have been raised in the foregoing discussion. The new photometer includes thermostatic control, to remove temperature effects; its receiving surface is cosine-corrected to an accuracy of ± 2%; other features of the design facilitate calibration and maintenance. Experience has shown that corrections for non-linearity can be embodied in a simple table, the contents of which require only infrequent laboratory checks, while routine calibrations can conveniently be carried out in situ against a portable sub-standard instrument.

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With regard to the accuracy of the standard of photometry, it was discovered that the opal glass used in the Mark II instrument did not act as a perfectly diffusing material, and this effect was then shown qualitatively by a suitably devised experiment. The extrapolation technique of calibration shows that a difference of 6% is involved. To ensure continuity of the Kew daylight record, simultaneous operation of the two instruments was started which, though not an entirely rigorous check, does substantiate the difference of 6% found in the laboratory. Certain other external evidence, which has also been reviewed, had previously suggested the existence of a systematic error of this sign and order of magnitude.

The design of the new instrument had developed largely from physical considerations of how best to bring the standard of natural daylight recording into line with the better established field of solar radiation recording. As well as providing qualitative data of general use to workers in many applied fields - biophysicists, agriculturists, electricity supply engineers, architects, paint and textile manufacturers, etc., - we are now in a position to use quantitative knowledge of a well-defined spectral component of the solar radiation. This can provide important contributions to the study of atmospheric absorption and scattering and to the wider problem of the planetary albedo.

8. Acknowledgments

We wish to express our thanks to Dr. G. D. Robinson for his help and encouragement throughout this work. Thanks are also due to Mr. H. D. Henley, who constructed and reconstructed the instrument several times, and to Mr. H. Heath, who completed the comparisons given in section 6 after our departure from Kew.

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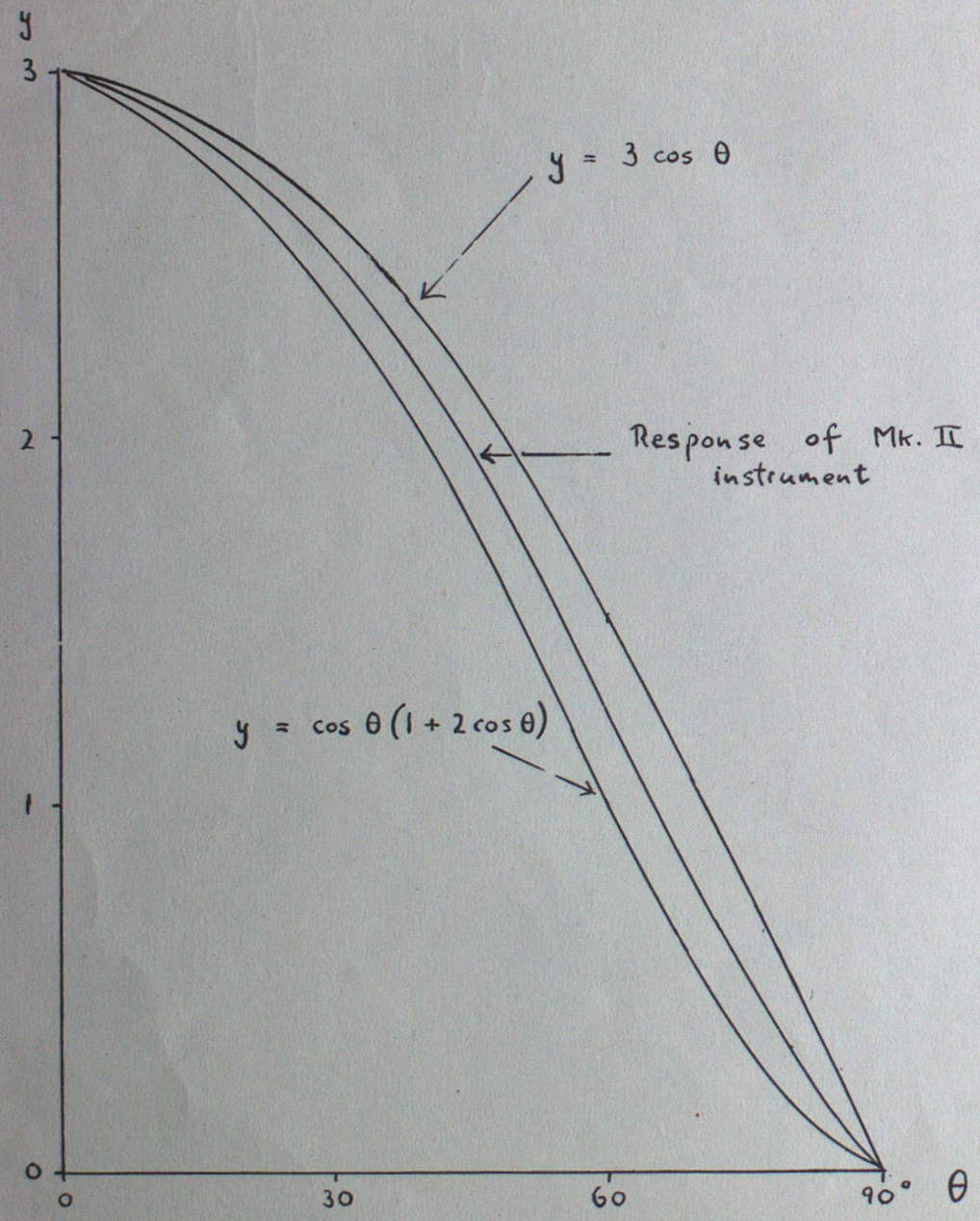

Fig. 1 - Response of Mk. II instrument.

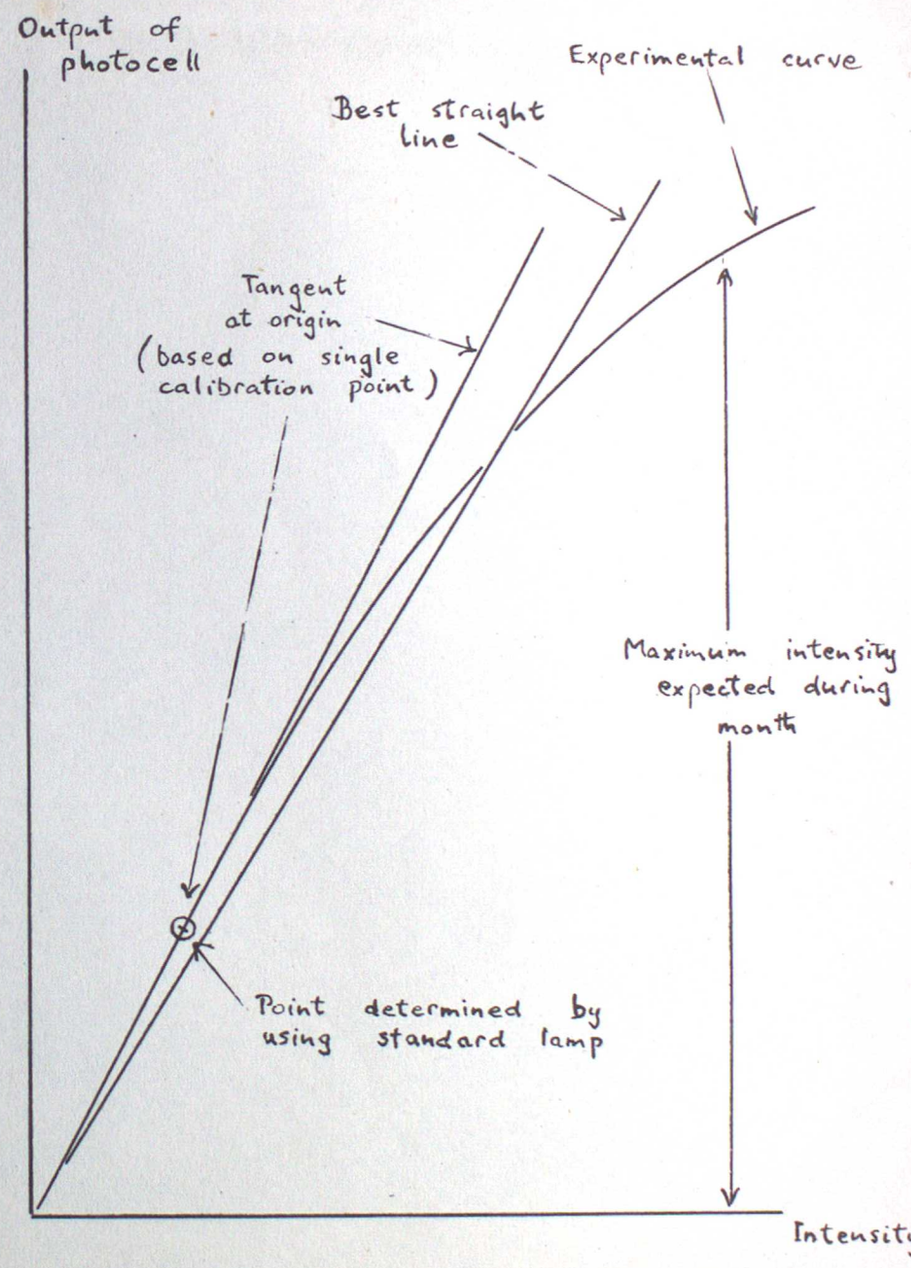

Fig. 2 - Correction for non-linearity.

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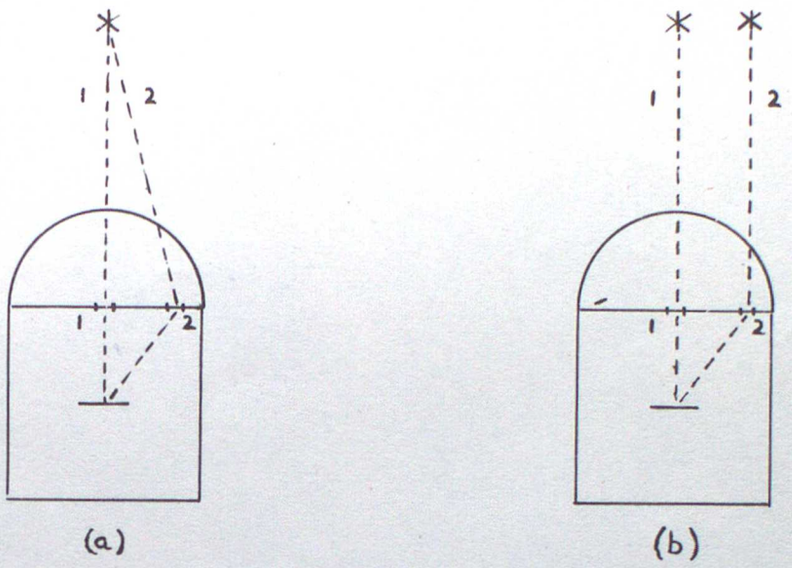
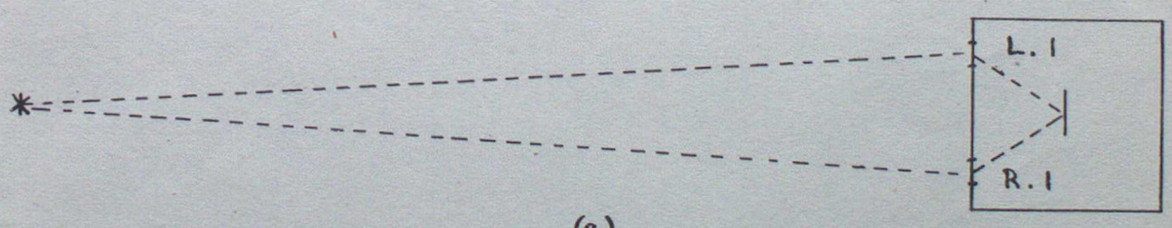


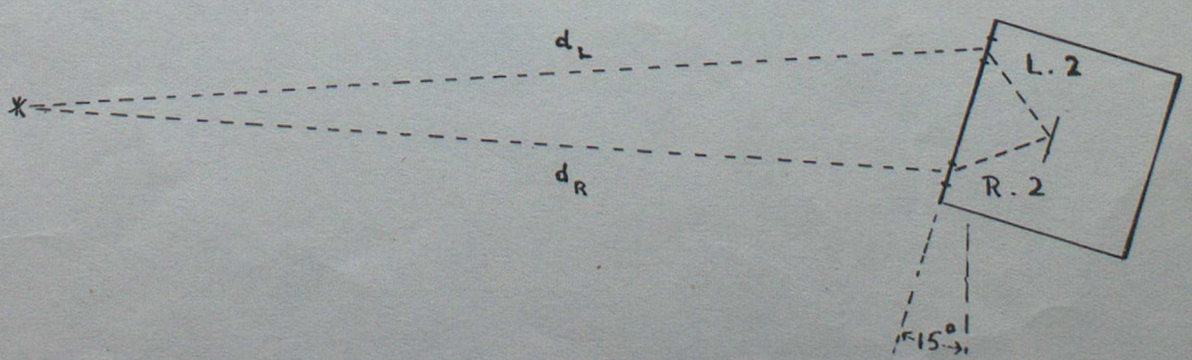
(a) (b)

Fig. 3 - Determination of illumination of the diffusing plate.



(a)

$$\left(\frac{R.2}{L.2} \times \frac{\cos \theta_L}{\cos \theta_R} \times \frac{d_R^2}{d_L^2}\right)\% - \left(\frac{R.1}{L.1}\right)\% \simeq 2\%$$



(b)

Fig. 5 - Test of diffusing properties of opal glass.

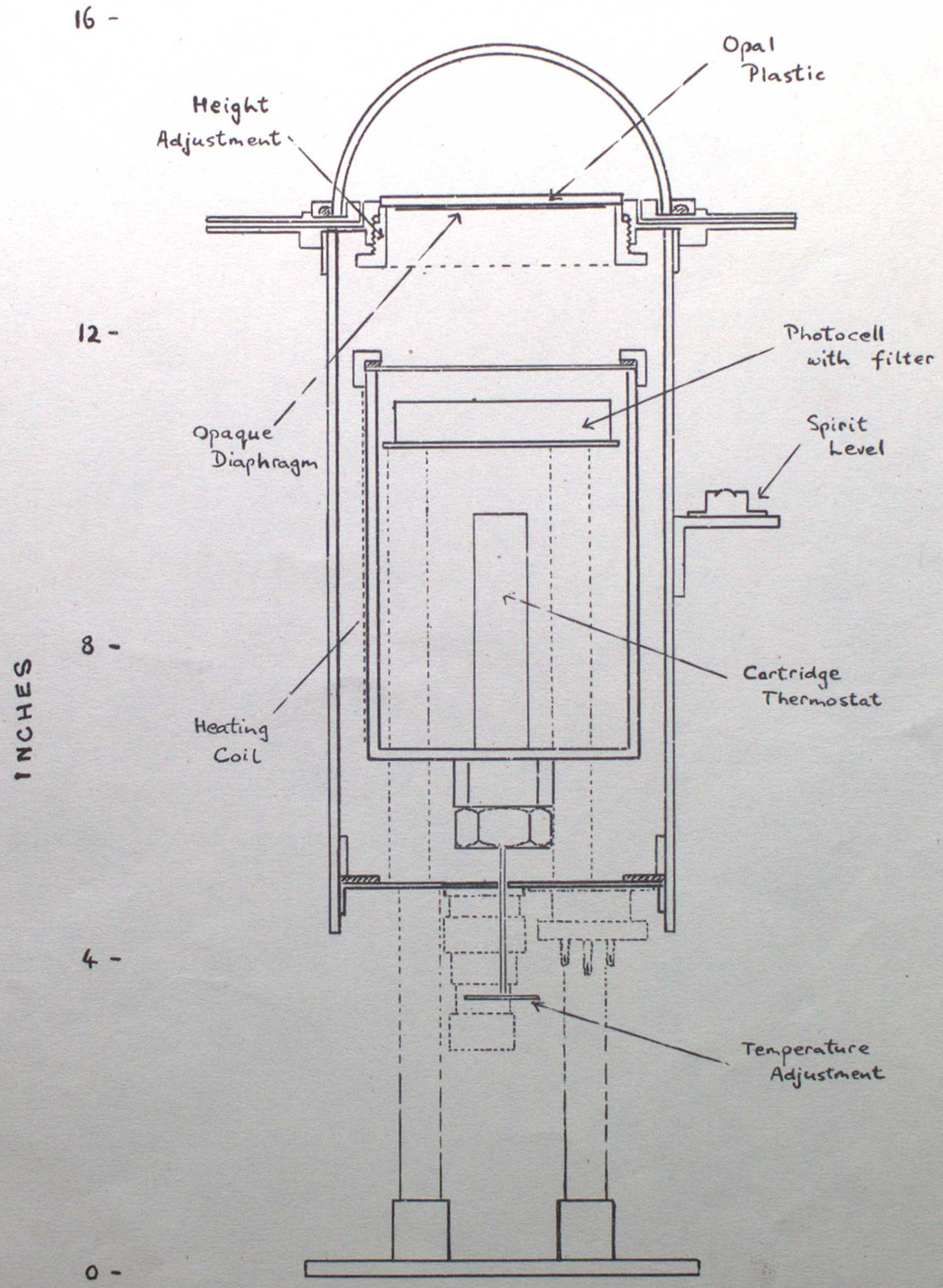


Fig. 6 - Daylight Recorder Mk. III.

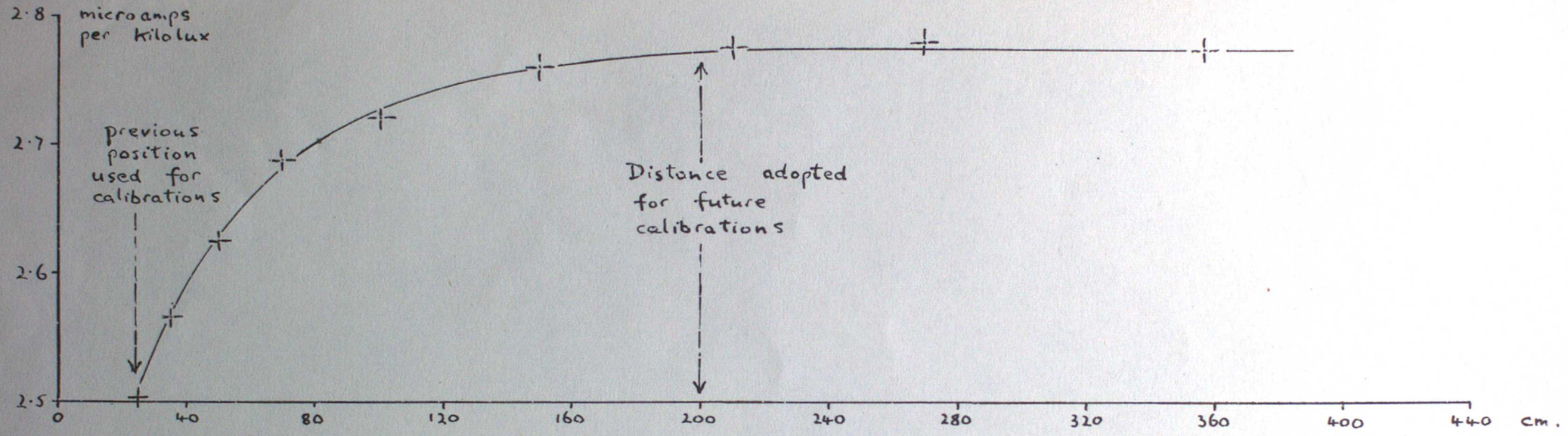
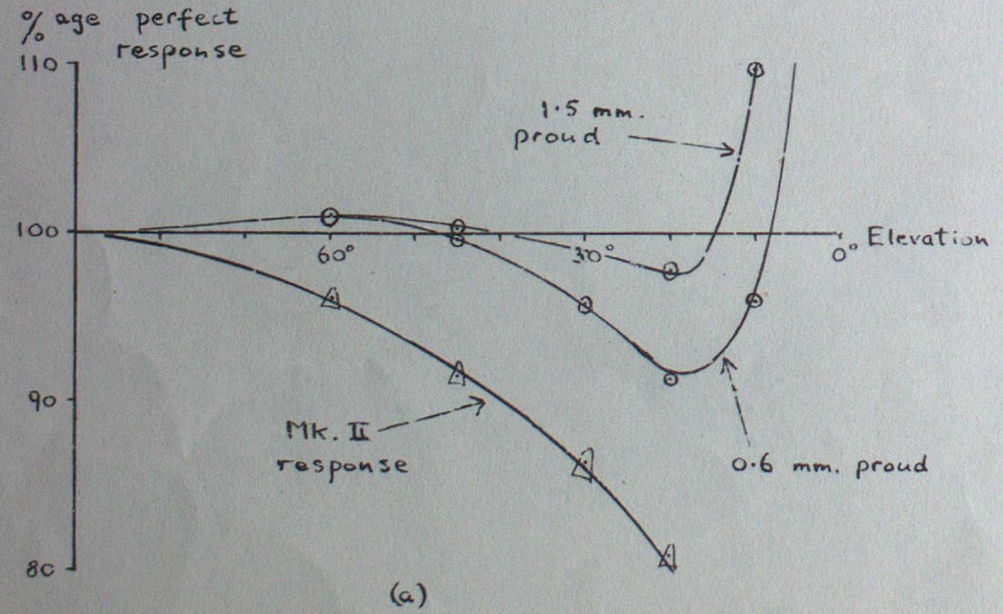


Fig. 4 - Calibration by the extrapolation method.



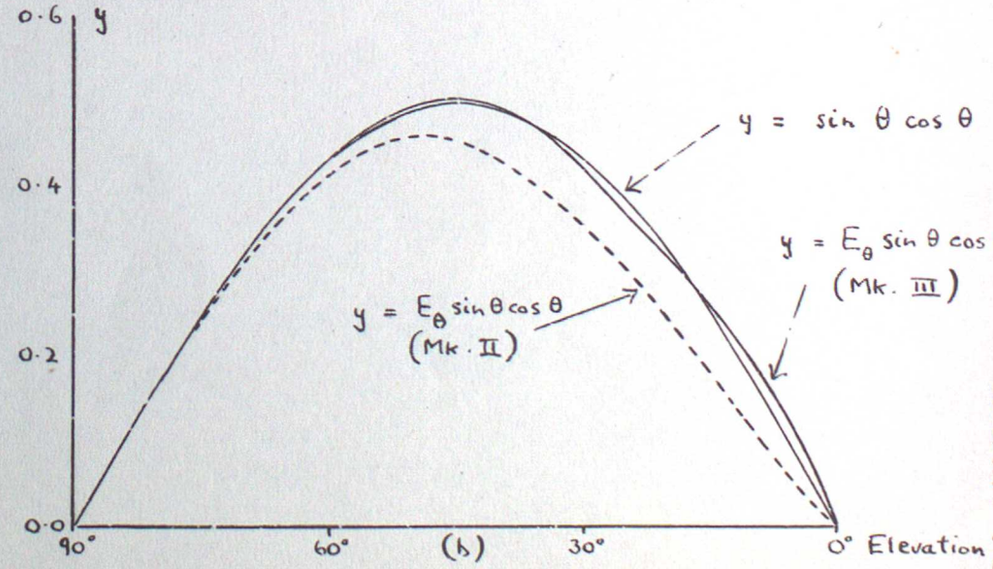


Fig. 7 - Effect of Mk. III cosine-correcting device.

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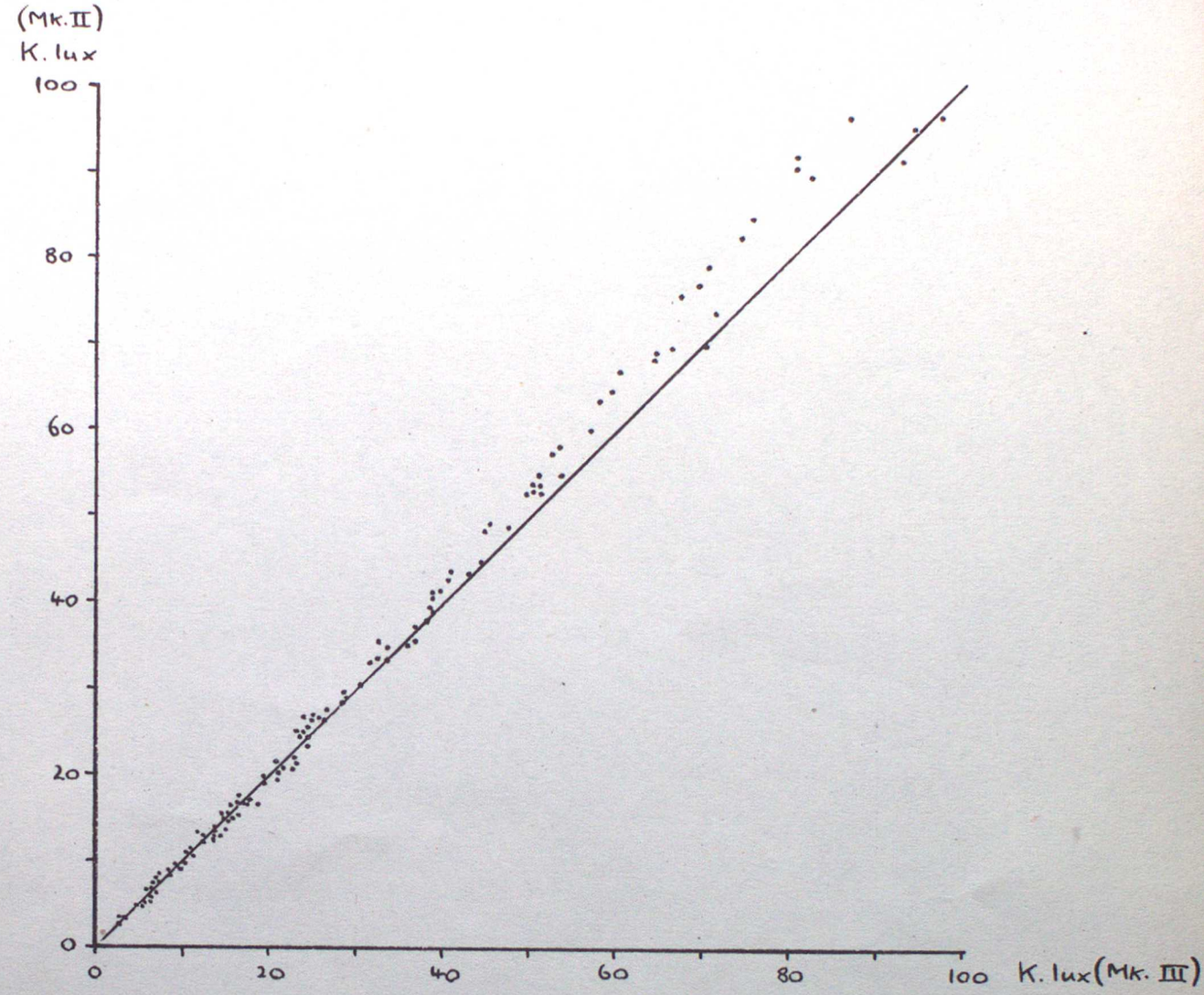

Fig. 8 - Mk. II v. Mk. III comparisons.